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A Review of Climate Change Impacts on the Ecosystem Services in the Saami Homeland in Finland

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Abstract

The aim of this work is (i) to study the observations of local reindeer herders about weather and climate change and their impacts on fell environment and reindeer herding, and (ii) to review the impacts of climate change on the ecosystem services in Sápmi, the Saami homeland in Finland. The focus of the study is on the impacts of climate change on those habitat, provisioning and cultural ecosystem services which are interconnected with the Saami way of life as Indigenous people and thus support the continuity of their culture. In the holistic world view of Arctic Indigenous peoples, material culture and non-material culture are not separated, and there is no boundary between nature and culture. However, cultural and spiritual meanings of ecosystems, species and landscapes are rarely taken into account in scientific research on ecosystems services. Our review indicates that both positive and negative impacts of climate warming on ecosystems and traditional livelihoods are to be expected in Sápmi. The most profound negative impacts will be on palsa mire and fell ecosystems, in particular snowbeds, snow patches and mountain birch forests. Consequently, changes in ecosystems may erode cultural meanings, stories, memories and traditional knowledge attached to them and affect the nature-based traditional livelihoods. In a situation where our rapidly changing climate is affecting the foundations of the nature-based cultures, the present review can provide a knowledge base for developing adaptation actions and strategies for local communities and Indigenous peoples to cope with changes caused by climate change and other drivers.

Keywords: Climate change, Ecosystem services, Sápmi, Provisioning ecosystem services, Habitat ecosystem services, Cultural ecosystem services

1. INTRODUCTION

Ecosystem services (ES) are the direct and indirect contributions of ecosystems to human well-being, supporting survival and quality of life (MA 2003). In the Arctic region, global change is affecting ecosystems' capacity to provide services in many ways: climatic warming is leading to alteration in ecosystems, natural resource exploitation is on the increase, and invasive alien species pose a threat to native biodiversity (Petersen 2009; Kroglund and Lundeberg 2017).

The global mean temperature is expected to rise by 1–5°C by the end of the twenty-first century (Stocker et al., 2013). Climate warming is strongest in the northern latitudes including the fell regions of Northern Europe (Larsen et al. 2014; Ruosteenoja et al. 2016b, 2016c). Winter air temperatures have already increased during the past 30–50 years in several locations (Kivinen et al. 2012; Kivinen and Rasmus 2015; Lépy and Pasanen 2017), and the snow season has become shorter (Rasmus et al. 2014; Luomaranta et al. 2019). Extremely cold weather events have declined in all seasons during the past 100 years, and extremely warm weather events have increased particularly in spring and autumn (Kivinen et al. 2017). The winter temperatures, the number of thaw days, and winter precipitation will increase further, while the occurrence of soil frost will decrease. Warm early winters with varying temperatures and events like rain-on-snow (ROS) or thaw and subsequent freezing may lead to more frequent icing of snow (Rasmus et al. 2016, 2018; Eira et al 2018). Snow melt occurs and the growing season starts earlier than before. The thermal growing season is lengthening and the effective temperature sum is increasing (Ruosteenoja et al. 2016a). The occurrence of the first frost in autumn will be delayed, and soil frost and snow cover will appear later than before (Venäläinen et al. 2001; Jylhä et al. 2009; Kellomäki et al. 2010).

Climate warming and its interaction with many environmental, social, economic and political drivers strongly affects the way of life of the Arctic Indigenous peoples (Näkkäläjärvi 2009; Turunen et al. 2017). For Indigenous peoples, ecosystem services and cultural continuity deeply intertwined and nature is the basis of everyday life (CAFF 2015).

Ecosystem services are generally categorized into four main types: 1. *Provisioning services* refer to the products obtained from ecosystems such as food, fresh water, wood, fiber, genetic resources and medicines; 2. *Regulating services* are the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, pollination or pest control; 3. *Supporting ecosystem processes and functions / habitat services* include e.g. nutrient cycling, soil formation, photosynthesis as well as genetic, species and habitat diversity; and 4. *Cultural ecosystem services (CES)* refer to non-material benefits that people obtain from ecosystems such as spiritual enrichment, intellectual development, recreation and aesthetic values (MA 2005; Kettunen et al. 2012; CAFF 2015). These categories are interconnected, in particular in the Arctic where extreme environmental conditions make the coupling between physical processes (e.g. snow, ice, weather, geomorphology, wind), biological processes (e.g. species interactions and primary productivity) and human processes (e.g. land use) very tight and visible (CAFF 2015). Moreover, in the holistic world view of Arctic Indigenous peoples, material culture and non-material culture are not separated, and in Indigenous ontologies, there is no boundary between nature and culture either: the two are intertwined and culture is everywhere (Harrison 2015).

In their review regarding the ES in European North (including Sápmi), Jansson et al. (2015) estimated that there will be a decrease in some of the culturally important species and, consequently, in cultural ties to the land in the future. Otherwise, cultural and spiritual meanings of ecosystems, species and landscapes are rarely included in scientific research regarding ES. This may be the case because cultural and spiritual values provided by ecosystems are difficult to assess (Kettunen et al. 2012). It has been noted that, in decision making in the Arctic and elsewhere, social and cultural attributes of ES are often given less emphasis than the economic benefits provided by ecosystems (CAFF 2015). Thus, more studies regarding the status of CES in the Arctic region are needed. Also, more attention should be paid to those provisioning ecosystem services which are important for continuity of Indigenous people's cultures, as climate change will affect the very foundations of their nature-based way of life. When dealing with nature-based cultures, the overlap between cultural and provisioning ecosystem services is evident. Provisioning ecosystem services are also cultural services, and often a prerequisite for a meaningful life. For the Saami herders, for example, the quality of life and the persuasion that being a reindeer herder forms the meaning of their life can be more important than economic income provided by the livelihood (Sköld 2015). Use of cultural and provisioning services, on the other hand, has an influence on some of the regulating and supporting services, e.g. reindeer grazing potentially affecting the climate through the albedo effect, and most certainly having an effect on the species biodiversity of the pastures.

In this article, we first present the results of the Webropol survey conducted by us on the observations of local reindeer herders of weather and climate change and their impacts on fell ecosystems and reindeer herding in Finnish Sápmi, and secondly, we present a review of the impacts of climate change on the ES in Sápmi addressed in recent literature. The focus of our study is on the impacts on habitat, provisioning and cultural ecosystem services which are interconnected with the Saami way of life as Indigenous people and support the continuity of their culture. This kind of information may be particularly valuable when the objective is to understand the interconnectedness of different ecosystem services, and to identify and develop strategies for local communities and indigenous peoples to help them mitigate and adapt to the changes caused by climate change and other drivers in the Arctic.

2.MATERIAL AND METHODS

2.1. Research area

Sápmi, the Saami homeland, is situated in northern Fennoscandia encompassing parts of Sweden, Norway, Finland, and the Kola Peninsula in Russia (Fig.1.). Finnish Sápmi is located in the area of the municipalities of Eanodat (Enontekiö), Ohcejohka (Utsjoki) and Anaar (Inari), and the northern part of Soađegilli (Sodankylä). The region comprises mostly of subarctic mountain birch forests, boreal coniferous forests along with fell heaths, bare fells and peatlands. The northern timberline of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) is located between latitudes 68º and 70º (Veijola 1998, Heikkinen et al. 2002). The climate of the region is subarctic. Annual mean temperature ranged in 1981-2010 from -1.9ºC to -0.8ºC, with a mean temperature in July between 11.2 and 13.9ºC and of January between -14.3 and -12.2ºC. Yearly precipitation varied between 433-606 mm. Approximately half of the annual precipitation falls as snow, which accumulates to a depth of 69-99cm (Pirinen et al. 2012). Interannual variation of temperatures and precipitation is high, and during the past 50 to 100 years, a significant warming trend has been observed (Vikhamar-Schuler et al. 2016; Kivinen et al. 2017).

The Saami people are the only Indigenous people of the European Union. The size of the Saami population is over 75,000 persons, of which approximately 10,000 live in Finland. Thirty-five percent of them live in Sápmi, the Saami Homeland, and 65% outside it. In Finland, there are speakers of three Saami languages: North Saami, Inari Saami and Skolt Saami (Saami Parliament 2019).

The Saami have traditionally practiced several different livelihoods, all strongly tied with the Saami way of life, in accordance with their close relationship with and respectful attitude towards nature. Different Saami groups have practiced different livelihoods depending on their residential environment. The traditional Saami livelihoods are fishing, gathering, hunting, Saami handicraft (*Duodji*) and reindeer herding (Saami Parliament 2019). Nowadays, however, it is common to practice other professions (e.g. in service and transport sectors) in addition to the traditional ones. Nature conservation supports livelihoods by sustaining jobs in conservation and by promoting nature-based tourism. Forestry grew rapidly in economic importance within the area in the early 20th century, but in the 21st century, nature-based tourism has become the economically most important business (Hallikainen et al. 2008; Jokinen 2014).

Reindeer herding is the most viable traditional livelihood in Sápmi. In Finland, Saami reindeer herding is practiced in the 13 northernmost herding districts (HDs) (Helle and Jaakkola 2008; Nieminen 2014; Näkkäläjärvi and Jaakkola 2017; Jaakkola et al. 2018) (Fig. 1). In Finland, both Saami and Finnish people practice herding; in Sweden and Norway this livelihood is mainly an exclusive right of the Saami. In Sápmi, the herds are bigger, herding is more often based on pastoralism and reindeer are not kept in enclosures, and supplementary winter feeding is not used as commonly as in reindeer herding practiced by non-Saami Finns. Saami reindeer herding represents a way of life deeply rooted connected in old traditions and values transmitted over generations. Herding functions as an important cornerstone of the Saami culture by offering both a language arena as well as materials for e.g. clothing and Saami handicrafts and ingredients for the traditional food culture (Näkkäläjärvi and Jaakkola 2017; Saami Parliament 2019). Saami reindeer herding is based on the Siida system, a traditional Saami socio-economic institution. A siida consists of either a single family or a certain number of households linked by kinship. It is both a social and a working community and can be seen as providing an endemic model of herding and social organization in Sápmi (Lehtola 2004; Riseth 2009; Mazzullo 2010). According to the Reindeer Herders' Association (2018), the largest permitted number of reindeer in the 13 northernmost HDs of Sápmi is 77,100. The number of reindeer owners in the Sápmi region is 1,232 (RHA 2018). Besides climate change, a number of other pressures such as increasing predator populations and land-use pressure have affected the livelihood (Pape and Löffler 2012; Pohjola and Valkonen 2012; Kumpula et al. 2014; Näkkäläjärvi and Jaakkola 2017; Jaakkola et al. 2018; Rasmus et al. 2019).

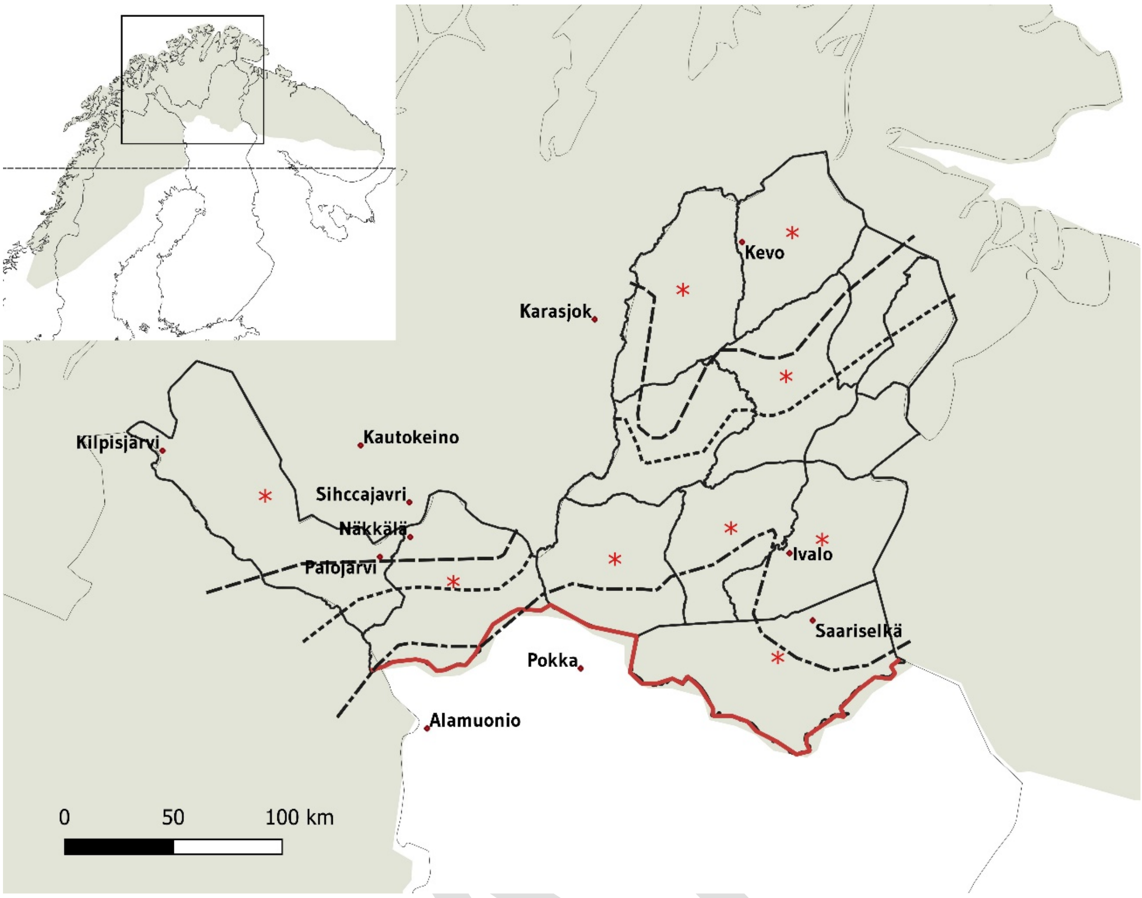

Figure 1. A Map of the Finnish Sápmi with 13 herding districts (HDs). The HDs whose herders responded to the survey are marked with an asterisk (*), and the locations of the weather stations in Finland and Norway whose long-term observations were compared with the herders' observations in Table 1. are indicated with a red dot. The map also shows the northern Norway spruce timberline (dashed-dotted line), Scots pine timberline (dotted line) and treeline (dashed line) (Heikkinen et al. 2002).

2.2. Survey

Local knowledge of reindeer herders is valuable since their experience of the weather and nature conditions of their HDs is often decadal and seasonal knowledge accumulated since childhood (Forbes and Stammler 2009; Vuojala-Magga et al. 2011). To develop a holistic understanding of the ongoing climate change and its effects on the northern environment and on the nature-based livelihoods of the region, we conducted a Webropol survey on the observations of weather and climate change and their impacts on reindeer herding. The local knowledge and observations of the herders were then compared with the long-term meteorological data recorded at the weather stations in northernmost Finland and Norway and analyzed in light of recent research literature (Fig. 1, Table 1.).

The survey was open between 13 October 2016 and 28 February 2017 (Supplementary file 1). The survey was designed in collaboration with Metsähallitus (The Finnish Forest Administration), Reindeer

Herders' Association (RHA), Finnish Environment Institute (SYKE), and Universities of Lapland and Jyväskylä. It was distributed to reindeer herders through the information services of RHA using its website, Facebook page, electronic mailing list and the professional journal *Poromie*s.

The survey was comprised of arguments presented for each of the seasons separately (Supplementary file 1). Arguments listed seasonal features of the weather (and in the fell area also of the vegetation) and addressed the experienced changes in these. A scale of 1 to 5 was used, where 1) "I have observed change in this feature into the direction of the argument"; 2) "I have observed some change in this feature into the direction of the argument"; 3) "I have not observed any change in this feature"; 4) "I have observed some change in this feature, but into opposite direction"; and 5) "I have observed change in this feature, but into opposite direction". Respondents also had the possibility to describe the changes more precisely and explain their consequent effects on herding.

The survey covered the period of the past 30 years (from 1980s to 2010s), but young herders who participated were instructed to consider the changes they had experienced during their whole life. A total of 90 herders responded the survey. Eighteen responses were received from nine HDs of the Sápmi: Ivalo, Hammastunturi, Kaldoaivi, Käsivarsi, Lappi, Muddusjärvi, Näkkälä, Paistunturi and Sallivaara (Fig.1). The average age of the respondents was 44 years. Seventy-two percent of them had reindeer herding as their main job and 28% as a part time job. The responses were analyzed for observed seasonal changes, experienced effects on the herding work and coping strategies employed because of these.

2.3. Literature Search Strategy

Our literature search was targeted at the following subject areas: 1) habitat ecosystem services (fells, mountain birch forests, pine forests and peatlands); 2) provisioning services (traditional livelihoods and cultural keystone species); and 3) cultural services (cultural identity, heritage and sense of place, traditional knowledge and nature as inspiration for handicraft and art). All these elements are important for maintenance of cultural continuity and identity of the Saami (Fig 2., Table 3). In the context of the present study, the term *cultural keystone species* refers to "salient species that shape in a major way the cultural identity of a people, as reflected in the fundamental roles these species have in diet, materials, medicine, and/or spiritual practices" as defined by Garibaldi and Turner (2004). After identifying the relevant literature, we conducted a systematic literature review. The publication types included in our review were research articles, book chapters and reports (also ones written in Finnish) published between 1998 and 2018. This time frame was selected as this is the period during which climate change research on the ecosystems, species and services has been widely conducted and published. We also included studies regarding the effects of climate change on Saami reindeer herding and studies addressing the effects of climate and related societal change on Saami traditional knowledge and cultural landscapes, including sacred sites. The literature search was performed both in English and Finnish using Google scholar and ISI Web of Knowledge. The keywords used in the search were scientific and common names of species/ecosystems/habitats combined into search strings with the words ”climate change”/”climate warming” and ”subarctic”/”Arctic. In addition, we searched for the following combinations of search terms: “status of ecosystem services, arctic”; “indigenous peoples, climate change, arctic”; “traditional knowledge, arctic, climate change”; “sacred sites/cultural landscapes, arctic, climate change”; “climate change, Saami reindeer herding/gathering/fishing”.

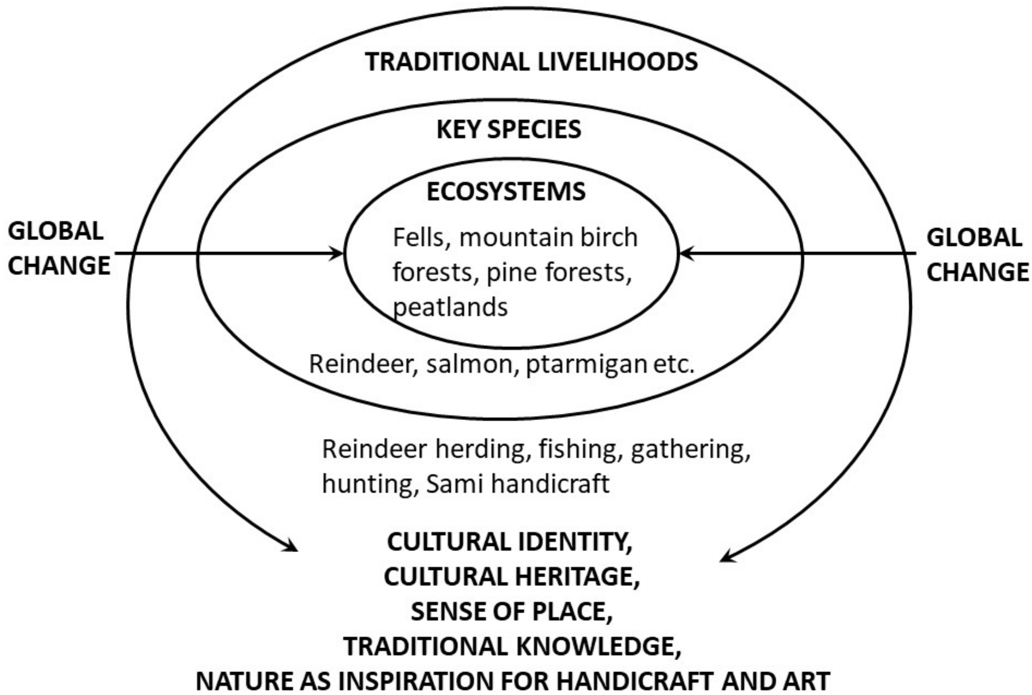

Figure 2. Key elements of the ecosystem services in Sápmi as a focus of the present study. Global change includes climate change and its interaction with a number of environmental, social, economic and political drivers.

3. RESULTS AND DISCUSSION

3.1. Reindeer herders’ observations of weather and climate

The herders in Sápmi (n=18) reported that summer weather has become more variable (Table 1). They notified that variation in the summer temperature and precipitation is large not only during the season, but also interannually. Nearly 80% of the herders reported that precipitation has increased during the past decades, and over 70% stated that heavy rainfalls are more common than earlier. Herders had not observed that summers would have become warmer, heat periods more common, cold periods rarer, wet snow or hail or draught more common (Table 1). According to the data recorded at the weather stations in Northernmost Finland, summers have become warmer in many locations, but no clear change can be detected in the amount of precipitation (Virtanen et al. 2010; Lépy and Pasanen 2017; Maliniemi et al. 2018) (Table 2).

Most of the herders reported that the sub-zero winter period starts later in the autumn, snow cover is formed later, the soil is freezing later and less than earlier (Table 1). Over half of the herders reported more frequent formation of mold on the vegetation. The herders' responses and the measurements of the weather stations indicated that there has been no significant change in the amount of precipitation in autumn. (Table 1).

The herders rather unanimously reported that winters are warmer than earlier and that the number of subzero days has decreased (Table 1). Their responses also indicated that winter weather has become more variable than before and winter rains are now more common than earlier. According to Kivinen et al. (2017), the number of extremely cold days has decreased in Northern Fennoscandia in all seasons. The herders' observations about the increased precipitation in winter and frequency of rainfalls in winter coincide with the meteorological observations of the weather stations (Vikhamar-Schuler et al. 2010; Rasmus et al. 2014; Kivinen et al. 2017; Lépy and Pasanen 2017).

Little over half of the herders pointed out that formation of ice on the soil below the snow (basal ice) is more common than earlier. Over 60% of them also reported more frequent icy layer formation within the snow cover. Eira (2012) has reported a trend of increased frequency of icing events over the last 30 years in Guovdageaidnu, in Norway, close to our research area. According to Rasmus et al. (2018), extensive formation of ice on the soil has occurred in the RMA in 16 years during 1948–2017. Basal ice was classified to be extensive when over 20% of the HDs informed ice formation on soil in their annual management reports. The fact that from these 16 winters of ice formation one third has occurred during the past ten years may suggest that the phenomenon is becoming more common (Rasmus et al. 2018). Moreover, although limited, other studies on the weather conditions preceding soil ice formation becoming more common may support this finding (Vikhamar-Schuler et al. 2010; Rasmus et al. 2014; Lépy and Pasanen 2017). The thickness of snow cover has not clearly changed on the basis of either the observations of the herders or the weather stations (Table 1 and 2).

Most of the herders reported that, nowadays, the frost period ends earlier in the spring, snow melts and snow-free patches are formed on the ground earlier, and the growing season starts earlier than was the case in the earlier decades (Table 1). These observations are mainly parallel with the long-term meteorological measurements conducted at the weather stations in Northernmost Finland and Norway (Table 2).

Table 1. The responses of the herders in Sápmi (n=18) to the arguments related to different seasons. Mean values of the responses and proportion of answers in the five classes are given. 1 = I have observed change; 2 = I have observed some change; 3 = I have not observed any change; 4 = I have observed some change,

but into opposite direction and 5 = I have observed change, but into opposite direction. Values ≤ 2 (bolded) mean that, on average, the herders have observed change/some change into the direction of the argument. Shading shows the classes in which the majority of responses fell for each argument.

	Mean	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
SUMMER						
Warmer summers	2,72	5,9	35,3	29,4	23,5	5,9
More frequent heat periods	2,89	5,9	17,6	47,1	23,5	5,9
More rare cold periods	2,83	5,9	17,6	52,9	17,6	5,9
More variable weather	**2,00**	27,8	44,4	27,8	0,0	0,0
Increased precipitation	**1,56**	58,8	17,6	23,5	0,0	0,0
More frequent heavy rainfalls	**1,61**	58,8	11,8	29,4	0,0	0,0
More frequent sleet or hail precipitation	2,61	11,8	17,6	58,8	5,9	5,9
More frequent droughts	2,83	5,6	27,8	50,0	11,1	5,6
AUTUMN						
Increased precipitation	2,33	17,6	29,4	41,2	11,8	0,0
Delayed frost season	**1,56**	55,6	33,3	11,1	0,0	0,0
Delayed snow cover formation	**1,61**	61,1	22,2	11,1	5,6	0,0
Delayed soil frost	**1,61**	47,1	35,3	17,6	0,0	0,0
Less soil frost	**1,89**	29,4	41,2	29,4	0,0	0,0
More frequent mold formation on the pastures	2,33	11,1	44,4	44,4	0,0	0,0
WINTER						
Warmer winters	**1,61**	50,0	38,9	11,1	0,0	0,0
Decreased number of frost days	**1,72**	38,9	55,6	0,0	5,6	0,0
More variable weather	**1,72**	55,6	16,7	27,8	0,0	0,0
More frequent formation of basal ice in the snow cover	2,39	11,1	44,4	38,9	5,6	0,0
More frequent formation of icy layers in the snow cover	2,17	22,2	38,9	38,9	0,0	0,0
Deeper snow covers	2,39	27,8	22,2	33,3	16,7	0,0
More frequent rainfalls	**1,83**	44,4	27,8	27,8	0,0	0,0
More snow-loads on trees	**1,61**	58,8	11,8	29,4	0,0	0,0
Increased windiness	2,11	27,8	33,3	38,9	0,0	0,0
SPRING						
Earlier discontinuation of the frost season	2,11	38,9	33,3	5,6	22,2	0,0
Earlier snow melt and earlier snow-free patches	**2,00**	33,3	44,4	11,1	11,1	0,0
Earlier start of the growing season	**1,83**	38,9	38,9	22,2	0,0	0,0

Table 2. Comparison of the observations of herders in the Sápmi (n=18) with the long-term observations of the weather stations in Finland and Norway. For locations of the weather stations, see Fig. 1.

Season	Herders' observations	Meteorological observations	Weather station	References
SUMMER	Summers are not warmer, hot periods are not more common, cold periods are not rarer	Summers are warmer	Kilpisjärvi, Palojärvi, Näkkälä, Alamuonio, Sihccajavri	Virtanen et al. (2010); Kivinen et al. (2017); Lépy and Pasanen (2017); Maliniemi et al. (2018)
	Summer weather is more variable	not studied		
	Summer precipitation has increased, hard rains are more common	No clear change in the amount of precipitation	Kilpisjärvi, Palojärvi, Näkkälä, Alamuonio, Sihccajavri	Kivinen et al. (2017); Lépy and Pasanen (2017); Maliniemi et al. (2018)
	Wet snow or hail are not more common	not studied		
AUTUMN	Frost period starts later	Autumns are warmer	Kilpisjärvi, Palojärvi, Näkkälä, Alamuonio	Lépy and Pasanen (2017)
		No clear change in autumn temperatures	Sihccajavri	Kivinen et al. (2017)
	Snow cover is formed later	The arrival date of snow cover is later	Alamuonio, Ivalo, Kevo	Rasmus et al. (2014); Luomaranta et al. (2019)
	Soil is freezing later and less	Surface temperature of permafrost has risen	Ridnitsohkka, Enontekiö	Vanhala and Lintinen (2009)
	Precipitation in autumn has increased	No clear change in autumn precipitation	Kilpisjärvi, Palojärvi, Näkkälä, Alamuonio	Lépy and Pasanen (2017)
		Precipitation in autumn has increased	Sihccajavri	Kivinen et al. (2017)
WINTER	Winters are warmer, number of subzero days has decreased, regional variation	Winters are warmer	Kilpisjärvi, Palojärvi, Näkkälä, Muonio, Saariselkä, Pokka	Rasmus et al. (2014); Lépy and Pasanen (2017); Maliniemi et al. (2018)
		No clear change in winter temperatures	Sihccajavri	Kivinen et al. (2017)
	Winter weather is more variable, formation of ice on the soil is not clearly more common	Number of days when temperature has passed 0°C has become more common	Kilpisjärvi, Palojärvi, Näkkälä	Lépy and Pasanen (2017)
		Number of days when temperature has passed 0°C has not become more common	Alamuonio	Lépy and Pasanen (2017)
		The number of days when average temperature is > 0°C or > 2°C has increased	Pokka	Rasmus et al. (2014)
		The number of days when average temperature is > 0°C or > 2°C has decreased	Ivalo	Rasmus et al. (2014)
		Number of mild and rainy periods has increased and they are more intense (measured by using several indicators)	Karasjok	Vikhamar-Schuler et al. (2016)
	Winter rains are more common	Winter precipitation has increased, higher proportion of precipitation comes down as rains	Palojärvi, Näkkälä, Kilpisjärvi, Alamuonio, Ivalo	Rasmus et al. (2014); Lépy and Pasanen (2017); Luomaranta et al. (2019)
		No clear change in winter precipitation	Sihccajavri	Kivinen et al. (2017)
	Thickness of snow cover has not clearly changed	Thickness of snow cover has not changed	Palojärvi, Näkkälä, Kilpisjärvi, Alamuonio,	Lépy and Pasanen (2017); Luomaranta et al. (2019)
		Snow cover is thinner	Ivalo	Rasmus et al. (2014)
SPRING	Frost period ends earlier in the spring	Springs are warmer	Kilpisjärvi, Palojärvi, Näkkälä, Alamuonio, Sihccajavri	Kivinen et al. (2017); Lépy and Pasanen (2017)
		Number of subzero days has decreased	Sihccajavri	Kivinen et al. (2017)
	Snow melts and snow-free patches are formed earlier, snow cover	Snow melt date is earlier	Ivalo, Kevo	Rasmus et al. (2014); Luomaranta et al. (2019)

	period is shorter, growing season starts earlier			
		No clear change in spring precipitation	Sihccajavri	Kivinen et al. (2017)
		Snow cover period is shorter	Kilpisjärvi, Palojärvi, Näkkälä, Alamuonio, Ivalo, Kevo, Pokka	Virtanen et al. (2010); Rasmus et al.(2014); Lépy and Pasanen (2017)

3.2. Climate change impacts on ecosystems in Sápmi

3.2.1. Fells and mountain birch forests

According to the survey, over 70% of the herders in Sápmi had observed reduced size of the late summer snow patches on the fells and over 60% of them had observed that they are rarer than previously (Fig. 3). One of the herders notified that: *”Long-term rainfalls melt late summer snow patches”*. Most of the herders had not observed any change in the extent or prevalence of the damage to mountain birch forests caused by geometrid moths compared to earlier. The herders also informed that fungal diseases, such as rusts and mold, have become more common in the reindeer forage plants during the last decades (Fig. 3).

Impact of warming on the expansion of coniferous trees upwards on the fell slopes depends on many factors and varies regionally (Pääkkö et al. 2018). Approximately 60% of the herders had observed expansion of coniferous trees into the open fells. One of the herders reported: *”Pine has expanded upwards. In Petsikko [place name], for example. You can look at the situation there today. You can see the pines in aerial pictures”*. Little over half of the herders in Sápmi had not observed shrubification (birch, willow) of the fells (Fig. 3). Instead, the positive role of reindeer was clear in the responses of many herders: *”Shrubification can be prevented by reindeer”*.

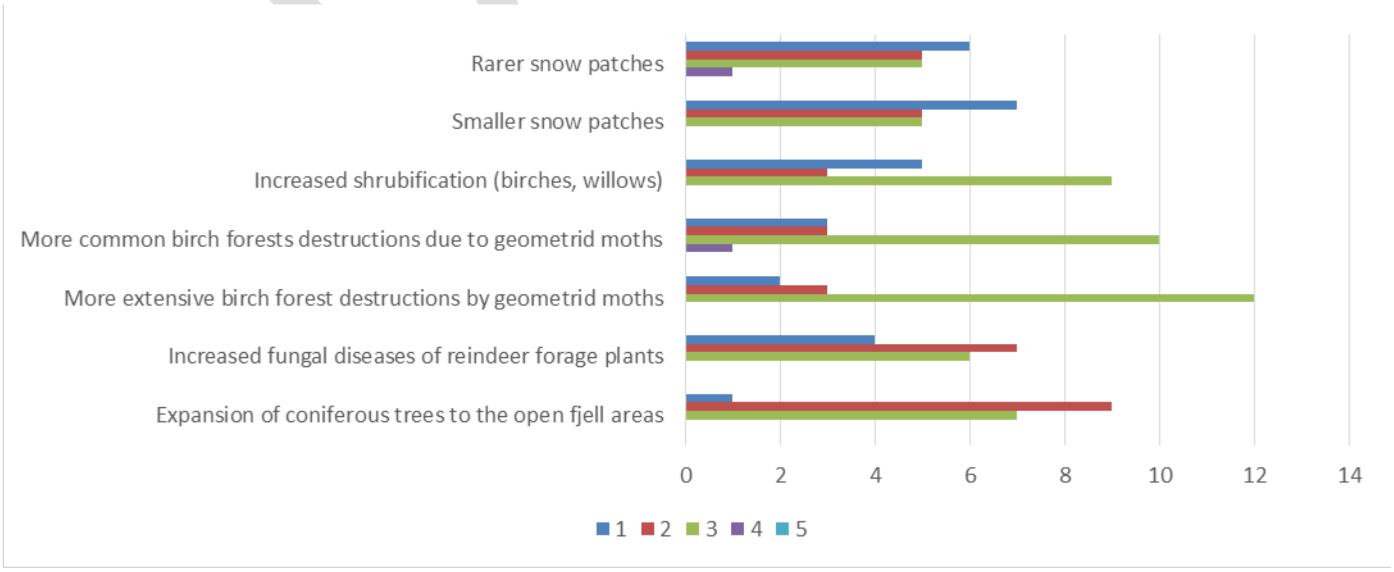

Figure 3. The responses of the herders in Sápmi (n=18) to the arguments regarding fells. 1 = I have observed change; 2 = I have observed some change; 3 = I have not observed any change; 4 = I have observed some change, but into opposite direction; and 5 = I have observed change, but into opposite direction. See supplementary file 1 for the complete arguments of the survey.

According to the assessment of threatened habitat types in Finland in 2018, climate change and reindeer herding and their combined effects are the most important factors affecting the status of fell habitats (Pääkkölä et al. 2018). A total of 53 fell habitat types were identified with a total area of 1.3 million hectares. Of all fell habitat types, 38% were estimated to be threatened (Kontula and Raunio 2018; Pääkkölä et al. 2018). The most threatened fell habitat types are snowbeds, snow patches and mountain birch forests (Björk and Molau 2007; Kivinen et al. 2012; Niittynen et al. 2018). In addition, with weaker frost, the status of habitats that need frost action will deteriorate. One fourth of the fell habitat types were assessed as near-threatened, but their area covers about a half of all the fell habitat types. Climate warming is causing a gradual overgrowth of bare fell habitats such as wide-stretching mountain heath types, because the coniferous zone timberline spreads into the fell area (Aakala et al. 2014; Matías and Jump 2014, 2015; Franke et al. 2015).

Mountain birch forests are important to Saami as they provide material for many different objects, for example traps, tools, sledges, boats, and other handicrafts, as well as for high-quality firewood (Aikio and Müller-Wille 2005). The use of birch is directly tied into the socio-spatial system of Saami by providing materials and fuel for running a household, building *laavus* (lean-tos) for shelter, traveling on land, and for hunting, trapping, fishing and reindeer herding (Aikio and Müller-Wille 2005; Vuojala-Magga and Turunen 2015). Mountain birch forests are regarded as having high aesthetic values among Saami, and the birch is also used for medicinal purposes (Aikio and Müller-Wille 2005). Mountain birch forests are vital pasture areas for reindeer. During winter, they support epiphytic lichens which provide forage when digging conditions for ground lichens are difficult. Birch forests also serve as avalanche barriers (Vuojala-Magga and Turunen 2015).

Climate warming is expected to enhance the growth and cover of mountain birch forests in Sápmi and to lead to expansion of forests to higher altitudes (Kullman and Kjällgren 2006; Truong et al. 2007; Kullman and Öberg 2009; Tømmervik et al. 2009; Kullman 2010; Post et al. 2011; Rundqvist et al. 2011; Callaghan et al. 2013). Due to variations in e.g. climate, soil properties and hydrology, a great regional variability in responses of mountain birch ecosystems is expected (Skre et al. 2002; Holtmeier and Broll 2005, Aune et al. 2011; Van Bogaert et al. 2011; Grau et al. 2012). Damage to mountain birch forests will become more common in the future. The number of extremely cold winter days will decrease, and thus, mass outbreak events of autumnal and winter moths (*Epirrita autumnata*, *Operophtera brumata*) are predicted to become more frequent (Kozlov 2008; Jepsen et al. 2008, 2011), because milder winters increase the survival rate of moth eggs (Virtanen et al. 1998; Virtanen and Neuvonen 1999; Logan et al. 2003; Klemola 2009; Ammunét et al. 2012). The outbreaks usually lead to defoliation and occasionally to widespread death of mountain birch trees over vast areas. In the 1960s, moth outbreaks destroyed about two-thirds of the mountain birch forests in northernmost Finland (Tenow 1972), and for example, in Utsjoki in 1964– 65, an area of 1350 km^2 was defoliated (Vuojala-Magga and Turunen 2015). New geometrid moth species are expected to spread into the area (Pääkkölä et al. 2018). Scarce umber (*Agriopis aurantiaria*) has been already observed to be spreading towards north (Nilssen 2007; Jepsen et al. 2011).

The decisive factor for the status of the habitats in Sápmi is the combined effect of climate change and grazing by herbivores (Cairns and Moen 2004; Moen et al. 2004; Cairns et al. 2007; Post and Pedersen 2008; Hofgaard et al. 2010; Aune et al. 2011; Eskelinen et al. 2016; Kaarlejärvi et al. 2013, 2015, 2017). Reindeer grazing is part of the fell nature. However, heavy year-round grazing pressure weakens the status of many fell habitat types, that of dry lichened fell habitats in particular. Heavy summer grazing weakens the renewal of mountain birch forests. Moderate grazing pressure can have beneficial impacts on biodiversity, particularly on herb-rich habitat types (Pääkkölä et al. 2018). The geometrid moth-caused damage increasingly often suffered by mountain birch forests discussed above constitutes an example of the interaction between climate change and herbivores. The recovery of birch forests from geometrid moth-caused damage has become more difficult in summer grazing areas because the reindeer eat the shoots and saplings, thus preventing the renewal of birch forests. This may gradually lead to disappearance of birch forests. Climate change and grazing may also have opposite effects and mutually compensate for each other's impacts. For example, on mesic mountain heaths and mountain meadows reindeer grazing may have positive effects, since it may prevent overgrowth of the habitat and maintain biological diversity. Since reindeer herding is practiced in the whole fell area, grazing has either positive or negative impact on almost all fell habitat types (Pääkkölä et al. 2018).

3.2.2. Pine forests

Scots pine forests, particularly old-growth forests rich in epiphytic lichens are important winter pastures for reindeer herding in Northern Fennoscandia (Kumpula et al. 2011; 2014). In Finnish Sápmi, a big proportion of the pine forests are located in conservation areas on state land. Part of the Saami practice forestry and get income from selling wood (almost 5% of productive forest land is privately owned) (Turunen et al. 2019). In Sápmi, pine wood is used for building (houses, cabins, reindeer fences etc.), firewood and handicrafts, for example.

Pine timberline (Fig.1) has started to advance in northernmost Finland at least hundred years ago due to climate warming after the Little Ice Age, but the expansion has been slow (Holtmeier et al. 2003; Sutinen et al. 2011). The conditions for distribution of pine have improved and most probably will improve further along with warmer summers (Juntunen and Neuvonen 2006; Aakala et al. 2014; Matías and Jump 2014; 2015). The results by Holtmeier et al. (2003) do not, however, support the assumption of fast rate of expansion of forests on the slopes of fells in Lapland. Pine forests and the fell habitats are affected by the interaction of summer temperatures, winter temperatures, precipitation, distribution of snow cover, wind conditions, soil conditions and grazing of herbivores, such as reindeer (Holtmeier et al. 2003; Sutinen et al. 2011; Matías and Jump 2015). Due to climate change, timberline is expected to move upwards on fells, where competition between conifer seedlings, shrubs and mosses for light and nutrients are not limiting factors (Autio and Colpaert 2005).

Franke et al (2015) studied changes in pine and spruce timberline during 26 years (1983–2009) in 13 different regions in northern Finland. It was found that the increase in the volume growth and the emergence of seedlings of spruce and pine were most probably due to longer growing seasons and increased atmospheric CO_2 concentration (Franke et al. 2015). Temperature sum and precipitation increased during the study period in Lapland particularly during 1994–2013 compared to long-term average values in 1977–2013 (FMI 2014).

On the other hand, changing climate may increase storm and snow damage (Gregow et al. 2011; Lehtonen et al. 2014), large temperature variation (Heikkinen et al. 2002) and favorable conditions for pests and diseases (Franke et al. 2015). Severe winter climate, drought and reindeer grazing can overrule the impacts of gradual warming (Holtmeier et al. 2003; Juntunen and Neuvonen 2006). The changes caused by reindeer grazing in soil and vegetation may have an impact on germination of seeds and establishment and growth of seedlings in many ways (Juntunen and Neuvonen 2006; Aakala et al. 2014).

3.2.3. Peatlands

Peatlands are important to the Saami as reindeer herding pastures and areas for berry picking. Impacts of climate warming on peatlands in northern Fennoscandia are the most profound and visible in palsa mires. Palsa mires are sub-Arctic peatland complexes with permafrost as a definitive character. Permafrost occurs within these mires in patches, in the form of high hummocks, and it is an essential part of these ecosystems, affecting hydrology, vegetation, and microhabitat and species diversity (Luoto et al. 2004). There is vast evidence that climatic warming causes permafrost thaw and degradation in sub-Arctic peatlands throughout northern Finland and Scandinavia (Matthews et al. 1997; Zuidhoff and Kolstrup 2000; Luoto and Seppälä 2003; Luoto et al. 2004; Fronzek et al. 2006, 2009; Fronzek 2013; Swindles et al. 2015; Borge et al. 2017).

Due to permafrost thaw, the hydrology and vegetation cover in palsa mires are changing. It has been documented that drier sites in palsa mires, which are dominated by dry hummock vegetation such as mosses and evergreen dwarf shrubs, have declined, and wet sites, dominated by tall graminoids, have expanded during the last three decades (Malmer er al. 2005; Bosiö 2012). This may mean more forage for the reindeer, but due to the increasing wetness of the mires, it may be more difficult for the animal to move around. In Nenets and Komi regions in Siberia, the thawing of the active layer of permafrost in summer is already affecting reindeer herding practices – e.g. choice of routes and campsites – as the thawing ground turns into mud which is hard to walk on and into which reindeer may even sink (Istomin and Habeck 2016).

Degradation of permafrost hummocks in peatlands is a visible sign of climatic warming, which changes the features of the landscapes. Slopes of palsa hummocks are known among the Saami and other local people as good cloudberry picking sites. However, even though there is an overall trend of decrease in cloudberry abundance, it remains unknown whether permafrost thaw impacts will be negative or positive (see section: Cloudberry).

Another common type of peatland in Sápmi are aapa mires, minerotrophic mires dominated by fen vegetation (Kaakinen et al. 2008). Climate warming is expected to cause hydrological changes in aapa mires, leading to ombrotrophication, i.e. the development of peatland from fen to bog, and changes in vegetation (Tahvanainen 2011). It has also been predicted that southern bog biotopes spread northwards as a result of climate change, and that raised bogs may replace aapa mires (Ruuhijärvi 2008; Tahvanainen 2011). Yet, topography and rainfall limit this development, and major ecosystem-scale responses to climate change are highly speculative (Tahvanainen 2011).

3.3. Climate change impacts on traditional livelihoods in Sápmi

3.3.1. Reindeer herding

The herders in Sápmi who participated in the survey reported that a cold and rainy summer is worse for reindeer herding than a dry and warm one. Delayed and poor development of vegetation can have a negative impact on milk production of the dam and, thus, the growth of the calf. A rainier – but warmer and longer – growing season may increase the growth of vegetation and availability of high-quality forage for the reindeer. During rainy summers, wet ground and flooding of rivers can make gathering and moving reindeer to the round-up sites more difficult. In addition, a lack of insect harassment, which is dependent on temperature and precipitation, can lead to poor aggregation for reindeer herds, which may complicate their moving to the round-up sites. Some of the herders stated that, so far, they have not observed any impacts of changes in summer weather on reindeer herding.

Reindeer – in particular calves – benefit from later onset of snow cover due to higher availability of forage, which allows for increased body weight and fitness as winter arrives. Many herders reported that variable and warm autumn weather may delay the timing and impair the intensity of rut. This and dispersal of herds due to lack of or thin snow can delay round-ups even until February. Instead of snowmobiles, terrestrial vehicles (ATVs) are more often used for collecting and moving reindeer. Some herders in Sápmi pointed out that, due to increased risk of poor digging conditions, the need for starting supplementary winter feeding of reindeer has increased.

There was variation in the responses of the herders in Sápmi regarding changes in winter. Some reported that digging conditions for the reindeer have deteriorated due to deep snow and ice formation, while others stated that the conditions have improved due to thinner snow covers. The herders who had experienced deteriorated digging conditions for the reindeer reported having employed various coping strategies. They had moved the herds to a more favorable location on the fells, reorganized the periods of time the herds are kept together, they had started moving reindeer from one pasture with hay to another earlier in the spring than before, they had started supplementary feeding, and monitored ice formation in soil and snow cover more regularly than before.

The herders reported the following changes in spring: earlier winter lasted "*as long as until May*", ice covers are nowadays thinner and they melt earlier, conditions for the use of snowmobile are worse due to early melt of snow and ice, flooding of waterbodies is not so strong due to evaporation of snow into the atmosphere, and birch leaf development occurs earlier than before. Herders informed that advanced arrival of spring has had a favorable impact on reindeer herding. Snow-free patches on the fells are available for reindeer earlier than before. Calves are fit during summer calf markings due to advanced development of vegetation. The observations of the herders reflect great variation among the years and uncertainty of the start of the growing season. Spring can also be difficult for reindeer on the fells: "... *it can snow heavily during the calving time, even in June a snowfall can result in a snowpack of 20-30 cm. Furthermore, strong flooding of rivers can lead to drowning of calves".*

The results of the survey conducted by us was in agreement with earlier studies that have shown that climate change has both favorable and unfavorable impacts on reindeer herding (Furberg et al. 2011, Turunen et al. 2016, Jaakkola et al. 2018, Rasmus et al. 2019). The longer growing season and increasing effective temperature sum (Ruosteenoja et al., 2015) mean densification and expansion of forests further north and upwards on the fell slopes, and changes in the quality, biomass and plant species composition of reindeer forage (Turunen et al., 2009). Increased outbreaks of geometrid moths can damage mountain birches and other reindeer forage plants (Jepsen et al. 2008) (see 3.2.1. Fells and mountain birch forests). Warmer summers with increased precipitation may lead to more severe insect harassment and more frequent parasite epidemics (Laaksonen et al. 2007, 2010; Härkönen et al. 2010). More frequent icing of snow may greatly decrease the availability of winter forage such as lichens for reindeer (Rasmus et al. 2016, 2018, Eira et al 2018). Increased occurrence of molds on pastures due to warmer autumns with snow cover formed on unfrozen soil can decrease the quality of winter forage (Kumpula et al. 2000, Rasmus et al. 2018). On the other hand, milder winter weather helps reindeer keep fit, and early snow melt and increased availability of fresh forage in the spring are favorable for lactating reindeer and their new-born calves (Kumpula and Colpaert 2003, Mårell et al. 2006, Helle and Kojola 2008, Turunen et al. 2009, 2016, Tveraa et al. 2013).

The coping strategies reported by reindeer herders for changing seasons are in agreement with those reported earlier (Furberg et al. 2011, Turunen et al 2016, Jaakkola et al. 2018, Rasmus et al. 2019). The strategies used by Sápmi herders differ from those used elsewhere in the RMA, however. For example, keeping reindeer in enclosures and feeding reindeer in the field is more intensive and has a longer tradition in southern and central part of the RMA compared to Sápmi. Also, the factors that impact herders' adaptive capacity vary greatly between the different HDs (Helle and Jaakkola 2008, Turunen and Vuojala-Magga 2014, Turunen et al. 2016, Jaakkola et al. 2018). Large, diverse and peaceful pasture areas in Sápmi give herders more choice regarding coping strategies during various weather conditions (Tyler et al., 2007; Peltonen-Sainio et al. 2017). Utilization of the diversity of pasture land may be limited if other land-use and human activity is intensive, or due to predator pressure (Anttonen et al. 2011, Pape & Löffler 2012, Turunen et al. 2017, Eira et al. 2018).

3.3.2. Gathering

Bilberry, lingonberry and crowberry

For [wild] berry species typically picked in Sápmi, both favorable (Bokhorst et al. 2008, 2011) and unfavorable (Jansson et al. 2015, Svensson et al. 2018) consequences from warming have been predicted. A review regarding ecosystem services in Norther Europe (Jansson et al. 2015) suggested that warming may lead to higher production of edible berries due to more pollination and earlier fruit development. Experimental studies have revealed, however, that winter warming increases the shoot mortality in lingonberry (*Vaccinium vitis-idaea*) and bilberry (*Vaccinium myrtillus*) and decreases flower and berry production in bilberry (Bokhorst 2008, 2011). Shoot mortality and decrease in crowberry (*Empetrum hermaphroditum*) have also been observed both in the experiments and in the field (landscape scale) after an exceptionally warm winter (Bokhorst et al. 2009). Another study reported that lingonberry, bilberry and crowberry abundance increased under long-term warming conditions, and warming resulted in a shift in dominance of lingonberry over bilberry in sub-Arctic birch forest (Svensson et al. 2018). These species seem to respond positively to warming under favorable snow conditions. However, bilberry is particularly vulnerable to both absence of winter snow and rapid loss of freeze tolerance from triggering of rapid spring-like bud burst during the winter warming event (Bokhorst et al. 2011; Taulavuori et al. 2013; Blume-Werry et al. 2016). Moreover, bilberry is negatively affected by moth outbreaks in birch forests, and, given its vulnerability to both frost drought and leaf defoliation, a decline in its abundance could be expected (Bjerke et al. 2017). However, bilberry also appears to have good capacity to compensate for the damage caused by winter warming by extensive re-growth of shoots (Bokhorst et al. 2011). In light of these findings, it seems that the frequency and timing of extreme warming events will be important factors structuring the dwarf shrub communities in the sub-Arctic, and consequently, ecosystem services provided by them.

Cloudberry

Cloudberry (*Rubus chamaemorus*) is the most valuable natural product in the gathering tradition of the Saami with high economic importance. Decline in cloudberry abundance has been reported from Finland

(Wallenius 1999) and other parts of the Arctic (Callaghan et al. 2005). Indigenous peoples living in Sápmi and northern Canada have documented damage to the berries due to warmer springs and summers (Huntington 2004; Helander-Renvall and Markkula 2011; Cuerrier et al. 2015). Changes in flowering phenology as a result of warmer springs have been documented by scientists in Northern Sweden (Aerts et al. 2004) and by Indigenous peoples in Nunavut, Canada (Cuerrier et al. 2015). Great variations in spring temperatures can lead to mismatch between time of flowering and abundance of pollinators. On European scale, modelled impacts of climate change on distributions of cloudberry were negative, suggesting less suitable habitats for the plant in the future (Harrison et al. 2006).

Cloudberry is commonly found in palsa mires, and therefore, in addition to direct effects of warming, thawing of permafrost will alter its distribution and abundance. Cloudberry commonly occurs at the edges of permanently frozen palsa hummocks in palsa mires. Thawing of the hummocks and consequent mineralization of permafrost increases the amounts of nutrients available for plants living around this thaw-front, and because plant production in permafrost peatlands is nitrogen-limited, increase in this nutrient affects net primary production and species composition (Keuper et al. 2017). Recent study found that the additional nitrogen uptake at the thaw front led to increased aboveground biomass of cloudberry (Keuper et al. 2017), suggesting that it may benefit from permafrost thaw. Malmer et al. (2005) observed a slight increase in cloudberry cover in a peatland in Northern Sweden after 30 years of successive degradation of permafrost. However, cloudberry does not tolerate very wet conditions, which will prevail on a later stage of permafrost thaw, leading to dominance of graminoids in the mires (see: Zuidhoff and Kolstrup 2005; Bosiö 2012; Gałka et al. 2018).

Garden angelica

Garden angelica (*Angelica archangelica*) is an important plant for the Saami, who have traditionally used it for food and medicine (Fjellström 2000; Inga 2008). The plant has been used as a treatment for many different diseases and has been referred to as "universal medicine" by the Saami (Pennanen 2000). Today, the plant is cultivated for commercial purposes and, for example, essential oils extracted from its roots are used to treat coughs and the flu. We found only a few studies regarding the effects of climate change on garden angelica. A couple of them suggest that it may expand to higher altitudes (Kaarlejärvi and Olofsson 2014) and latitudes (Pospelova et al. 2017) in a warmer climate. However, competition with other species may inhibit the effects of warming (see Marberg 2013; Kaarlejärvi and Olofsson 2014).

3.3.3. Fishing: Atlantic salmon

Freshwaters are particularly vulnerable to climate change because water temperature and availability are highly climate-dependent and because species have limited ability to disperse when the environment changes (Woodward et al. 2010). Complex climate change induced stressors are at play in freshwaters: shifts in temperature regimes, increase in frequency, intensity and/or duration of droughts, floods and extreme flow events, and altered snow and ice cover, and extension of permafrost (ACIA 2005; IPCC 2007; AMAP 2011; Wrona and Reist 2013).

In Arctic Biodiversity Assessment, Wrona and Reist (2013) listed several projected impacts of climate change on the physical, chemical and biological characteristics of aquatic freshwater ecosystems: disruption or alteration of life-history phenology (timing of reproduction), shifts in the onset and duration of the growing season, species invasions, species range extensions and changes in regional distribution and abundance patterns, shifts in relative abundances of co-occurring life-history types (e.g. migratory versus resident char) and ecological types (e.g. limnetic forms of fish versus benthic forms), distances between refugia (e.g. water oases), changes in ecosystem primary, secondary and bacterioplankton production, changes in the occurrence /or shifts in the intensity and frequency of structuring/geomorphological processes (e.g. extreme flow events, floods, fires), changes in biogeochemical cycles related to fluctuations in catchment hydrology (alterations in precipitation/evaporation patterns, permafrost thaw and deepening of the active layer), and changes or declines in water availability and/or hydrological connectivity that can lead to loss of critical habitat (Prowse et al. 2006; Reist et al. 2006a, 2006b; Wrona et al. 2006; Heino 2009; Woodward et al. 2010).

For the Saami, salmon fishing has always been – and still is – a fundamental part of their culture and economy, in particular in the River Deatnu (Tana), a river running on the northern border between Finland and Norway (Pedersen 2009; Helander-Renvall and Markkula 2011; Holmberg 2018). There are long traditions in salmon fishing and the skills and knowledge related to it are passed on from older to younger generations within families (Helander-Renvall and Markkula 2011). Salmon fishing is also important for emotional well-being of the Saami (Nousuniemi 2001). Atlantic salmon can thus be defined as a cultural keystone species.

The impacts of changing climate are complicated for anadromous fish species, because they must cope with a variety of habitats and conditions during their lifecycle (Heino et al. 2016). Climate change is predicted to have both positive and negative effects on salmonid species abundance in the subarctic and Arctic region (Friedland and Todd 2012; Hedger et al. 2013; Jansson et al. 2015). Jansson et al. (2015) estimated mixed effects, including higher survival and reproduction in some species and temperature stress in others, habitat loss in cold adapted species and competition from warm adapted species. When modelling the impacts of future climate change on the juvenile stage of *Salmo salar*, Hedger et al. (2013) found that the climate scenarios resulted in lower parr (young fishes which have not yet migrated to the sea) abundance in Northern Norway. However, when the complete life cycle of salmon was modelled, an increase in abundance in, both in marine and freshwater stages was predicted (Hedger et al. 2013). Finstadt et al. (2004) also found negative effects of climate warming on Atlantic salmon juveniles, when testing the impacts of ice conditions on food consumption and metabolism. Under semi-natural conditions the lack of ice cover induced strong negative effects on the energy budget. And because energetic deficiencies are assumed to be an important cause of winter mortality, the study indicated that ice break-ups or removal following climatic change may affect winter survival of salmon significantly, particularly in northern populations (Finstadt et al. 2004).

Jonsson and Jonsson (2009) predicted that milder and wetter winters, more precipitation falling as rain and less as snow, decrease in ice-covered periods and frequent periods with extreme weather, could cause earlier migration of salmon within the season, younger age-at-smolting and sexual maturation, and increased disease susceptibility and mortality. Also, Otero et. al. (2014) found that the start of salmon migration has occurred 2.4 days earlier per decade since the 1960s, associated with changes in temperature. They concluded that global warming can lead to a reduced connection between the cues for migration and the environmental conditions in the receiving marine environment with potential implications for salmon survival. Also, growth opportunities might be reduced if emigration timing does not match with the production of prey that are experiencing changes in their own phenology, inducing further food web alterations (Otero et al. 2014).

3.3.4. Hunting: Willow ptarmigan

There are long traditions in willow ptarmigan (*Lagopus lagopus*) trapping among the Saami (Helander 1999). Ptarmigan bones have been found from Saami offering sites (Salmi et al. 2015) and the bird also appears as a motif in Saami drums (Kjellström 1991). Ptarmigan trapping is still an important subsistence activity for the Saami and provides economic income for a small number of hunters (Metsähallitus 2017). The future trends in ptarmigan populations in Northern Europe are predicted to be negative (Jansson et al. 2015; Kozma et al. 2017). There is a worldwide decrease in populations of many grouse species, including the willow ptarmigan (Henden et al. 2011). The threats to the willow ptarmigan populations include ungulate (reindeer and elk) over-browsing on willow shrubs which ptarmigans heavily depend on as food and shelter, habitat fragmentation, and collision e.g. with power lines and fences (Storch 2007; Ims et al. 2007; Henden et al. 2011; den Herder et al. 2013; Lagerholm et al. 2017). Local declines in willow ptarmigan populations have also been linked to moth outbreaks in mountain birch forests (Hovelsrud et al. 2017).

Climate change impacts on global populations of willow ptarmigan are most likely negative. The range size of the willow ptarmigan is predicted to decrease under warming climate (Kozma et al. 2017). It is probable that, during the warmer and wetter winters, the proportion of dry and porous snow in the snow cover will decrease and that of thaw-freeze/icy snow will increase (Rasmus et al. 2004, 2016). These kinds of snow conditions are unfavorable for all birds with a behavioral adaptation to seek shelter in the snow cover during low temperatures (burrowing). Moreover, the willow ptarmigan is adapted to harsh and cold environments of the arctic and high-alpine areas (Martin and Wiebe 2004), and high summer temperatures have been found to limit its reproduction (Selås et al. 2011). Climate change may also alter predator–prey interactions, leading to decrease in ptarmigan populations (Henden et al. 2017).

3.4. Climate change impacts on cultural ecosystem services

3.4.1. Cultural identity, heritage and sense of place

Cultural identity, heritage and sense of place are manifested in cultural landscapes. The Saami cultural landscape is often described as an invisible part of the landscape, or a spiritual landscape layer (Magga 2007; Ojanlatva and Neumann 2017). In cultural landscapes, memories, stories and meanings are attached to different places. The Saami culture has not left many visible marks in the nature, and thus, an essential aspect in their cultural landscape is the knowledge embedded in it: who uses different areas and when, when to cross rivers safely, what are the rules and limits for resource use, and where are the animal paths, berry-picking areas, sacred sites and pasture areas located (Magga 2007).

As discussed in earlier sections, climate warming will alter the landscape in Sápmi in many ways. Together with impacts of climatic change on Saami livelihoods, this will affect the cultural landscapes and ties to the land. Previously, Jansson et al. (2015) noted that decline in populations of culturally important species and landscape transformations will lead to deterioration of cultural ties to the land in the future in Nordic areas. According to our review, climate warming will have negative effects e.g. on willow ptarmigan populations and cloudberry production, and both negative and positive effects on mountain birch, Atlantic salmon and reindeer herding. Earlier studies have indicated that, for people living from the land, any ecological change, such as changes in species composition and diversity, or landscape structure, may reduce their cultural and social ties to the land (e.g. Forbes et al. 2011; Jansson et al. 2015; Jaakkola et al. 2018).

When physical landscapes change, stories, memories and meanings may also change or fade away. The Saami sacred sites, which play an important part in their culture and identity, are a good example. Sacred sites are mostly naturally shaped land patterns such as fells, hills, capes, lakes or islands, or unmodified natural objects, such as rocks, trees, boulders, small lakes or springs, or human-made or modified structures, such as offering rings made of stones, wooden piles or erected stone structures (Carpelan 2003; Ojanlatva 2013). Sacred sites also serve as offering sites, called *sieidis* in the Saami language. A common characteristic of indigenous peoples' sacred places is their functional aspect (Ojanlatva and Neumann 2017). The sites may serve e.g. as spirit residences, ceremonial areas, traditional landmarks, questing sites, legendary and mythological places, burial sites and traditional resource areas (Carmichael et al. 1994). Present-day archaeological finds give evidence of both continuing traditions and new meanings attached to sacred sites (Äikäs and Spangen 2016). According to Ojanlatva and Neumann (2017), sacred sites were part of the pre-Christian conception of the world of the Saami, carrying beliefs of the presence of ancestors and other spiritual beings. Thus, if a sacred site is altered or destroyed, all the meanings and the history connected to that place are lost with it.

It is challenging to estimate the direct impacts of climate warming on cultural landscapes and sacred sites, as there are many different issues at play simultaneously. According to Heinämäki and Herrmann

(2017), Arctic indigenous peoples' ancient areas are increasingly at risk due to rising development activities, such as growing tourism, extractive industries (e.g. mining, oil and gas), industrial forestry and infrastructure development. Warming climate can create an additional pressure for land use and development in the Finnish Sápmi, due to e.g. projected increase in transport and Arctic shipping and growing tourism. An example of this kind of development is the planning of the Rovaniemi-Kirkenes railway which would cross traditional Saami lands and has, thus, created a lot of controversy (The Barents Observer 2017; Saami Council 2018).

In protecting indigenous peoples' sacred sites, legislation plays a key role (see Heinämäki and Herrmann 2017). In Finland, the Antiquities Act (1963) is the main piece of legislation which protects sacred sites. There are approximately 50 registered sacred sites which are regarded as 'ancient monuments' and protected under the Antiquities Act. The majority of them are located in northernmost Finland (Ojanlatva and Neumann 2017). However, there are many sacred and other sites – important for Saami cultural identity and sense of place in Sápmi – which are not covered by the Antiquities Act (1963), yet vulnerable to changes in environment and increasing land-use pressure.

3.4.2. Traditional ecological knowledge (TEK)

The Saami traditional knowledge is deeply intertwined with the surrounding environment and is manifested in relationships with nature and in terminology used in reindeer herding, fishing, gathering, hunting and traditional handicraft. To acknowledge indigenous peoples' close relationship with nature, the term *traditional ecological knowledge* (TEK) is often used when referring to knowledge held by them. The term refers to cumulative knowledge of the local environment and ecosystems. TEK is defined as "a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes 1993), encompassing language, naming and classification systems, resource use practices, rituals, spirituality and worldview. TEK is also an aspect of indigenous peoples' connection to the land (Helander-Renvall 2014).

There is ongoing concern about the worldwide decrease of traditional lifestyles and related knowledge (e.g. ECOSOC 2005; Saamelaiskäräjät 2006). Previous studies have noted the deteriorating effect of climate change on traditional livelihoods and related knowledge of Saami and other Arctic Indigenous peoples (ECOSOC 2005; Nuttall 2007; Laidler et al. 2009; Furberg et al. 2011; Adger et al. 2013; Aslaksen et al. 2017; Jaakkola et al. 2018). Changes in livelihoods and traditional practices can lead to loss of terminology and practice-based knowledge. For example, Jernsletten (1997) has showed that there was once rich terminology related to Saami seal hunting that has completely disappeared.

Climate change can affect TEK through loss of predictability and by creating a need for new adaptation actions. Supplementary winter feeding is an example of an adaptation action which can have negative cultural effects and may erode reindeer herders' TEK (Jaakkola et al. 2018). In our survey targeted at the Finnish Sápmi fell areas, some herders pointed out that, due to increased risk of poor digging conditions created by ice formation on top of snow, the need for supplementary winter feeding of reindeer has increased.

Loss of predictability may occur when TEK no longer corresponds with the changing conditions and reality. It has been pointed out in previous research that problems related to access to forage and health or condition of reindeer can emerge so quickly – or are such recent developments – that there are no existing coping strategies or knowledge available (Peltonen-Sainio et al. 2017). Thus, in rapidly changing conditions, TEK related to these issues may lose its value (Eira et al. 2018). In their study among the Saami in Sweden, Furberg et al. (2011) demonstrated that the traditional knowledge of reindeer herders no longer corresponded with reality when changes in surrounding environment were occurring too fast: "New, previously unknown phenomena such as precipitation in severely cold weather and drastic temperature variations over short periods of time are occurring and the old weather signs are no longer reliable. Herders are now being forced to do the opposite of what old, unwritten rules have always said, such as staying out on the mountains all winter or migrating to the summer grazing lands at the wrong time."

However, it should be emphasized that TEK is evolving and living knowledge, based on constant observation of, and interaction with, the surrounding nature. It is land-based knowledge, which contributes to adaptive capacity in changing climatic conditions (Pearce et al. 2015). As stated by Cruikshank (2005), TEK is produced and expressed in human encounters, not encapsulated in closed traditions. It has also been argued that in the era of climate change, knowledge held by Indigenous peoples, which is based on constant observations and connection with nature, can respond to changes very rapidly, and even change faster than scientific knowledge (Krupnik and Ray 2007). In the current situation, adaptation of Saami reindeer herders to climate change requires both traditional knowledge, and new, context-situated learning and knowledge, which is accumulated and exchanged within the herding community (Turunen & Vuojala-Magga 2014).

It should also be noted, that to keep TEK as living and evolving knowledge, protection of the species and ecosystems in Sápmi – as well as the Saami languages – is needed. If there is a decrease in diversity of species and ecosystems, a decrease in diversity of expressions in TEK concerning these will follow. TEK can also be maintained only if languages carrying the knowledge are still spoken as part of everyday activities. According to UNESCO Language Atlas (2011), two of the Saami languages spoken in Finland, Inari and Skolt Saami, are "severely endangered". North Saami can also be regarded as an endangered language, as most of the speakers of that language live outside Saami homeland (Seurujärvi-Kari 2014).

3.4.3. Nature as inspiration for handicraft and art

Inspiration for human creative thought and work is defined as one type of cultural ecosystem service (CAFF 2015). In the Saami context, this type of CES is closely connected to *duodji*, Saami traditional handicraft.

The making of *duodji* has a long history, and it is inherently tied to the Saami nature relations (Valkonen and Valkonen 2014). Nature provides inspiration, themes and materials – such as bone, leather, wood and other plant material – for handicrafts. Traditionally, *duodji* was about making functional everyday articles such as clothes, utensils, boats, and sacred objects, but today it is also a form of art (Koslin 2010).

The materials for handicrafts are collected at a certain time of the year, and thus, the making of *duodji* follows nature's rhythm (Näkkäläjärvi and Juntunen 2015). The decorations and colors express nature's phenomena such as northern lights or autumn foliage. TEK plays an important role in the making of *duodji:* the skills and experiences are passed on through practice as teaching and learning often take place when several generations make handicrafts together (Helander-Renvall and Markkula 2017). The making of *duodji* is closely connected to the ecosystems and other traditional livelihoods in Sápmi. Thus, for example moth outbreaks or felling of forests can change the landscape, which can function as inspiration for *duodji*, but, at the same time, these changes can make it more difficult to obtain wood material for practicing it. Moreover, many of the materials used in *duodji* come from reindeer, and therefore, factors affecting reindeer herding affect the possibilities to practice *duodji*.

The impacts of climate warming on the Saami practice of *duodji* are multiple and can occur through changes in landscape, species distributions and/or reindeer herding practices. Also, if the warming climate creates more pressure for external land-use and development in the Finnish Sápmi, possibilities of practicing *duodji* will diminish. Already today, many areas where materials have traditionally been gathered for handicraft, are now open to external land-use activities (Helander-Renvall and Markkula 2017).

4. CONCLUSIONS

According to the survey on the observations of local reindeer herders about weather and climate change and their impacts on fell environment and reindeer herding conducted by us among reindeer herders in the Finnish Sápmi, and the findings of the literature review undertaken in this study, both positive and negative impacts of climate warming on ES in Sápmi can be expected (Table 3). Of habitat services, fell areas and peatlands are particularly vulnerable to climate change impacts. The preservation of the fell habitat types requires further enhancing action taken towards mitigating climate change. Also, further research efforts should be targeted at monitoring the changes in the biodiversity of fell habitats and at finding the causes and effects for such changes. To reduce the harm caused by heavy grazing of reindeer, the team of fell habitat experts of the Assessment of the Threatened Habitats in Finland in 2018 proposes regulation of grazing pressure and the development of pasture rotation where possible (Pääkkö et al 2018). The rapidly growing tourism in northernmost Finland, utilization of natural resources and other plans for land use increase the pressures in different parts of the fell area. Therefore, the fell habitats and their state must be protected by means of comprehensive land use planning.

Both palsa and aapa mires are listed in Annex I of the Bern Convention as endangered natural habitats. Both of these peatland types are considered to be very vulnerable to impacts of climate change (Kaakinen et al. 2018). Thus, it is important to protect the peatlands in Sápmi to preserve both endangered habitats and the Saami way of life, to which these ecosystems contribute as reindeer pastures and berry-picking areas. Palsa mires are rather well protected in Finnish Sápmi as most of them are situated in protected areas, such as protected wilderness areas or Natura 2000 sites. However, these ecosystems are directly affected by warming climate through permafrost thaw, and thus, without mitigation of greenhouse gases these ecosystems cannot be preserved.

In the holistic worldview of the Saami, nature and culture are intertwined. This is also reflected in the interconnectedness of habitat, provisioning and cultural ecosystem services. All the ecosystems treated in this article are also cultural landscapes, and changes in these ecosystems will alter peoples' sense of place and erode cultural meanings, stories, memories and traditional knowledge attached to them. Alterations in ecosystems affect traditional livelihoods, which consequently leads to a loss of terminology and practice-based traditional knowledge. Thus, protection of ecosystems, habitats and species Finland has committed to in international conventions (e.g. Convention on Biodiversity 1992) is also about preserving Saami culture.

Moreover, these threatened ecosystems provide regulating and supporting services, e.g. climate regulation, nutrient cycling, soil formation and photosynthesis. Northern peatlands store one-third of all carbon on Earth, more than any other terrestrial ecosystem (Davidson and Janssens 2006; Dise 2009) and thus play an important role in global carbon cycling. Permafrost thaw can increase the decomposition of peat, leading to release of greenhouse gases such as carbon dioxide and methane to the atmosphere (Christensen et al. 2004). Shorter period of snow cover and advancing tree line in fell areas create a positive feedback mechanism, due to changes in land surface and albedo.

It should be noted here that legislation and regulations related to resource use and practice of traditional livelihoods play a central role in protecting the viability of ecosystem services in Sápmi. The rights of Saami as Indigenous people are protected by the Constitution of Finland (1995), which guarantees the Saami cultural and linguistic autonomy and the right to maintain their own culture and language. The Act on the Saami Parliament (974/1995) requires authorities to negotiate with the Saami Parliament in "all far-reaching and important measures which may directly and in a specific way affect the status of the Saami as an indigenous people". A similar obligation to consult is also required e.g. by the Reindeer Husbandry Act (848/1990), and Mining Act (621/2011). However, there is controversy regarding the legislation and regulations of resource use. One example of this is Saami reindeer herders' long-standing demand that the Finnish Reindeer Husbandry Act (848/1990) – which does not recognize reindeer herding as a cultural right of the Saami and their traditional Siida system – should be amended (Heikkilä 2006; Müller-Wille et al. 2006; Heinämäki et al. 2017; Markkula et al. 2019, for definition of Siida*,* see section 2.1. Research area). Salmon fishing regulations constitute another example. Salmon fishing in the River Deatnu is regulated by a bilateral agreement between Finland and Norway, and the new fishing regulations imposed in the summer of

2017 were strongly opposed by the Saami population. The regulations were criticized for severely limiting the traditional fishing technique involving weir and net practiced by the Saami, while lighter limitations were set for tourist fishing (Holmberg 2018). Thus, the Saami livelihoods in Finland are affected by multiple issues – climate warming being one of them.

Finally, we want to emphasize that both scientific knowledge and observations of local people about weather and nature conditions are valuable, since climate warming has direct impact on different ESs, such as the traditional livelihoods. When local/traditional knowledge and scientific knowledge are combined, it is possible to arrive at both holistic and in-depth understandings of the interaction between nature and humans.

Table 3. Summary of the importance and expected impacts of climate change on ecosystem services in Sápmi. + = positive impact; – = negative impact.

Ecosystem service	Importance	Expected impact	Reason
Habitat service			
Fells	Pasture areas	–	Gradual overgrowth of bare fell habitats, as the coniferous forest expands into the fell area
Mountain birch forests	Pasture areas, handicrafts, firewood	+	Increased growth and biomass
		+	Expansion to higher altitudes
		–	Increased moth outbreaks, damage to birches
Pine forests	Pasture areas, epiphytic lichen important food for reindeer during winter	+	Increased growth
		–	Increased occurrence of storms, pests
Peatlands	Pasture areas, berry picking areas	–	Extensive permafrost thaw
Provisioning service			
Reindeer herding	Traditional livelihood	–	More frequent ice formation on soil and snow, decreased availability of winter forage
		–	Increased occurrence of mold on pastures
		+	Milder winters help reindeer to keep fit
		+	Early snow melt, increased availability of fresh forage in the spring favorable for lactating reindeer and calves
Gathering	Traditional subsistence activity	–	Increased moth outbreaks, damage to birches
		+	Increased forest growth
		+	Longer growing season
		–	Decrease in berry production due to warming and draught
Cloudberry	Food, well-being	–	Decrease due to summer warming and draught
Other berries	Food, well-being	+	Earlier fruit development, higher production
		–	Decreased growth due to winter warming
Garden angelica	Traditional plant used as medicine and food	+ (?)	Unsure, few studies available
Atlantic salmon	Cultural keystone species	+	Increased abundance
		–	Lower winter survival of juveniles
		–	Increased disease susceptibility
Willow ptarmigan	Cultural keystone species	–	Decrease due to habitat loss
Cultural service			
Traditional knowledge	Passing culture on to younger generations	–	Changes in traditional livelihoods, decrease in biodiversity
Cultural identity, heritage and sense of place	Cultural meanings and stories embodied in landscapes	–	Decrease in biodiversity, changes in physical landscape
Nature as inspiration for handicraft/art	Duodji is an integral part of Saami culture	?	Multiple effects, difficult to estimate

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Supplementary file 1

Survey targeted at reindeer herders: changes in snow and weather conditions during the past 30 years

Reindeer herders typically have decadal experience, accumulated since childhood, of the natural conditions of their herding district and covering all seasons of the year. The aim of this survey is to collect local knowledge about weather and climate as well as their impact on nature and reindeer herding from those working in reindeer herding. The survey relates to the most recent 30-year period. Each argument considers a change which has happened during the past 30 years. A young respondent can think of the changes he/she has observed during his/her whole lifetime. The arguments have been classified according to seasons. You can respond to the arguments by choosing the most suitable option. In the free text fields, you can describe more precisely the changes that you have observed and write about their impacts on reindeer herding in your herding district. After having completed the survey, you can save and send your response by choosing the “Submit” option. It takes 15 minutes to respond to the survey. The data will be handled confidentially so that it is not possible to identify individual responses. The results of the survey will be used in an ongoing assessment of the threatened habitats, particularly the fell habitat types. The survey is also a part of ongoing research “Changing operational environment of reindeer herding” at the University of Jyväskylä and the Arctic Centre of the University of Lapland. The results will be published in the professional journal Poromies. The survey has been designed in co-operation with Metsähallitus (Lapin luontopalvelu), Reindeer Herders Association, Finnish Environment Institute (SYKE), the Arctic Centre, and the University of Jyväskylä. Thank you for your response!
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1 Herding district

2 Year of birth

3 Reindeer herding
Herding is my full time job
Herding is my part time job
I am not a herder

4 Are there fells in the region of your herding district?
Yes/No

5 Arguments related to the changes in spring
Subzero/frosty period ends earlier in the spring
Snow melts and snow free patches formed earlier in the spring
Growing season starts earlier

Alternatives
1) I have observed change
2) I have observed some change
3) I have not observed any change
4) I have observed some change in this feature, but into opposite direction
5) I have observed change in this feature, but into opposite direction.

6. Free-form description of the changes in spring

7. How have changes in spring affected reindeer herding?

6 Arguments related to the changes in summer
Summers are warmer than before
Hot periods are more common
Cold periods are rarer than before
Summer weather is more variable than before
Precipitation amount has increased
Heavy rains are more common
Summer drought is more common than before
Wet snow and hail are more common than before

Alternatives
1) I have observed change
2) I have observed some change
3) I have not observed any change
4) I have observed some change in this feature, but into opposite direction
5) I have observed change in this feature, but into opposite direction.

9. Free-form description of the changes in summer

10. How have changes in summer affected reindeer herding?

11.Arguments related to the changes in autumn
Precipitation amount has increased
Subzero period starts later in the autumn
Snow cover is formed later
Soil is frozen later
Soil is frozen less than before
Mold formation on vegetation is more common than before

Alternatives
1) I have observed change
2) I have observed some change
3) I have not observed any change
4) I have observed some change in this feature, but into opposite direction
5) I have observed change in this feature, but into opposite direction.

12. Free form description of changes in autumn

13. How have changes in autumn affected reindeer herding?

14. Changes in winter
Winters are warmer than before
The number of subzero days has decreased
Winter weather is more variable than before
Formation of basal ice on soil is more common than before
Formation of icy layers in snow cover is more common than before
Snow covers are thicker than before
Winter rains are more common than before
Accumulation of snow and hard rime on tree branches is more common than before
Winters are windier than before

Alternatives
1) I have observed change
2) I have observed some change
3) I have not observed any change
4) I have observed some change in this feature, but into opposite direction
5) I have observed change in this feature, but into opposite direction.

15. Free-form description of the changes in winter

16. How have changes in winter affected reindeer herding?

17. Arguments related to the fells (no need to respond if there are no fells in the region of your herding district)
The permanent or late summer snow patches are rarer than before
The permanent or late summer snow patches have become smaller
Shrubification (birches, willows) has increased on the fells
Destruction of mountain birch forests due to geometrid moths (autumnal moth, winter moth) are more common than before
Mountain birch forest areas destructed by geometrid moths (autumnal moth, winter moth) are more extensive than before
Fungal diseases, including rust and mold, of reindeer forage plants have increased
Coniferous trees have expanded to the open fell areas

18. Free-form description of the changes in fell areas

19. How have these changes affected reindeer herding?